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Variations in image magnification due to mask repositioning in a 1:1 projection printer

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VARIATIONS IN IMAGE MAGNIFICATION DUE TO MASK REPOSITIONING IN A 1:1 PROJECTION PRINTER

by

Sarah M. Dolan

A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the school of
Photographic Arts and Sciences in the
College of Graphic Arts and Photography
of the Rochester Institute of Technology

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ABSTRACT

A Perkin-Elmer Micralign 230 Exposure Tool was used in an analysis of magnification variation. In the analvsis, all elements were kept constant except for the repositioning of the mask between sets of wafers that were exposed. Repositioning was initiated by removal and replacement of the mask from the exposure tool and the mask holder. Overlay measurements were then taken from the exposed wafers. These measurements were used to calculate the amount of magnification error of the images found on the wafers. These magnification values verified the hypothesis that repositioning of the mask has a significant effect on magnification values.

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INTRODUCTION

In the experiment, a Perkin-Elmer Micralign Model 230 Projection Mask Alignment System was used as an exposure tool. Samples were exposed on the tool as follows. A mask and wafer were loaded into the tool. They were manually aligned prior to exposure by the correct placement of fiducial marks as seen through the viewing optics.[1] The amount of exposure the wafer received was a function of the scan speed and the intensity of illumination at the wafer.[2] The scanning mechanism moved the mask and the wafer simultaneously in an arc past the projection optics.

These optics consisted of a spherical concave primary mirror, a spherical convex secondary mirror, and three flat folding mirrors (R1,R2,R3), as seen in Figure 1.[3] Illumination from a high-pressure mercury lamp was directed by condenser optics to the mask. An arc-shaped slit allowed only a small portion of the mask to be illuminated at one time to prevent distortion and aberrations. The projection optics then transfered the image of the illuminated portion of the mask to the corresponding portion of the wafer.[4] The amount of illumination on the wafer was adjusted by changing the exposure aperture, and the exposure time was varied by the scan speed.

The Model 230, introduced in 1979,[5] was claimed to be able to accurately project mask images onto a semiconductor

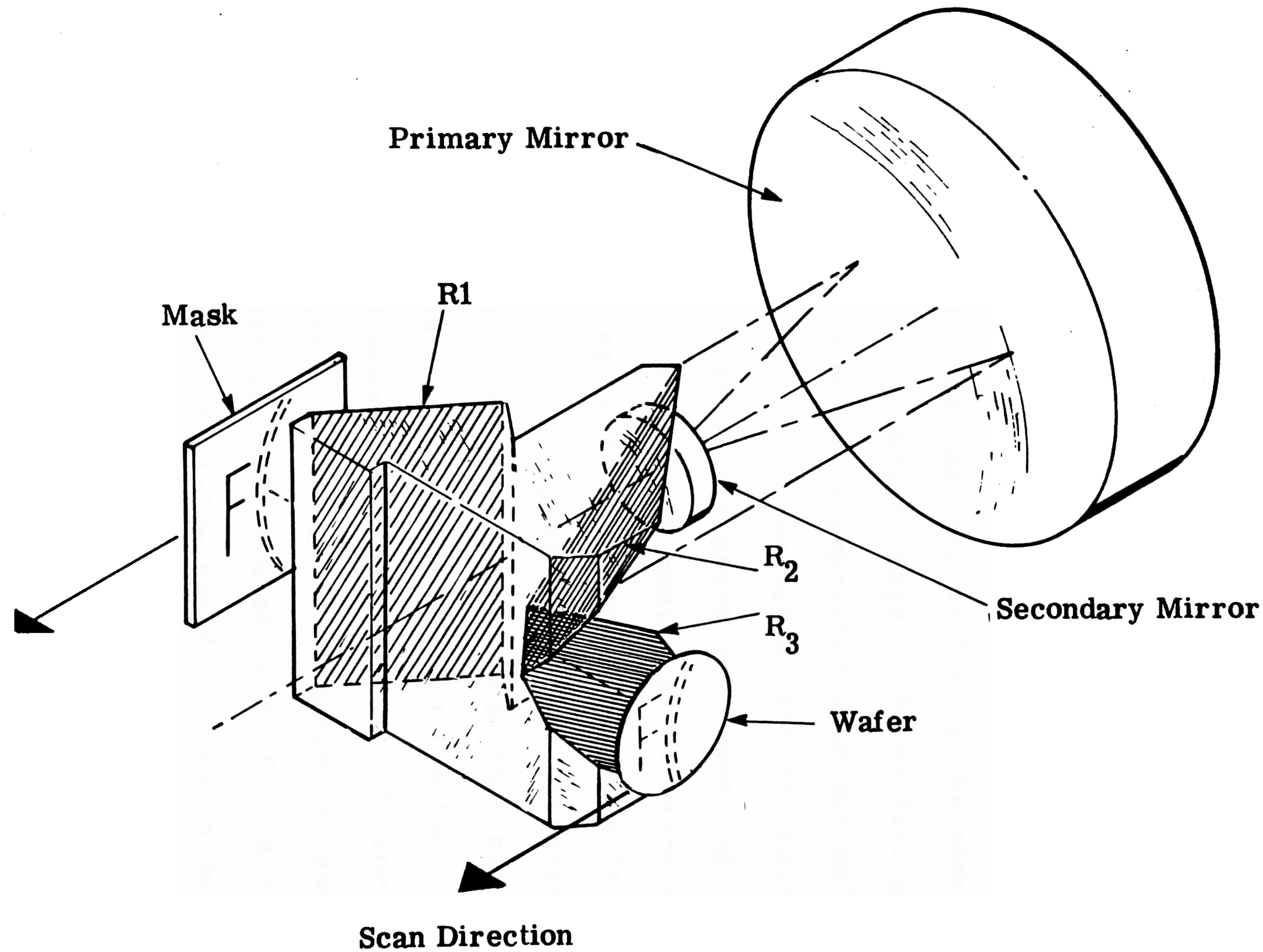

Figure 1 . Reflective Projection System with Folding Mirrors.[12]

wafer with at 1:1 magnification ratio.[6] In theory, there is no variation between the size of the image on a mask and that projected onto a wafer. However, in many tool-to-itself overlay studies, certain types of magnification errors have been found.[7]

Tool-to-itself overlay studies are conducted by making two exposures on the same wafers, utilizing the same mask and exposure tool. The resist image produced during the first exposure is permanently imprinted onto the wafers by etching an underlying SiO2 layer subsequent to resist development. After resist stripping and recoating, a second image is impressed into the new resist by exposure and development. The degree to which the two images fail to coincide(known as the overlay error) can be measured by various means. The overlay error data can then be used to obtain the relative magnification between the two images.[8]

With standard measurement and analysis of overlay error data a magnification error of ± .1 microradians can be detected.[9] Magnification errors of up to five microradians are typically found in tool-to-itself studies in spite of the fact that the same mask, wafers,and exposure tool are used. Furthermore, variations of several microradians of magnification error are found from one experiment to the next, again in spite of nominally identical experimental conditions.

A possible explanation for variation in magnification errors in tool-to-itself studies relates to the positioning of the mask with respect to the tool optics, during the two exposures. The relative arrangement of the mask, tool, and wafer is shown in Figure 2. When $Rm=Rw$, mask points O,P,Q are projected onto the wafer at O',P',Q' as the carriage traverses angle θ.

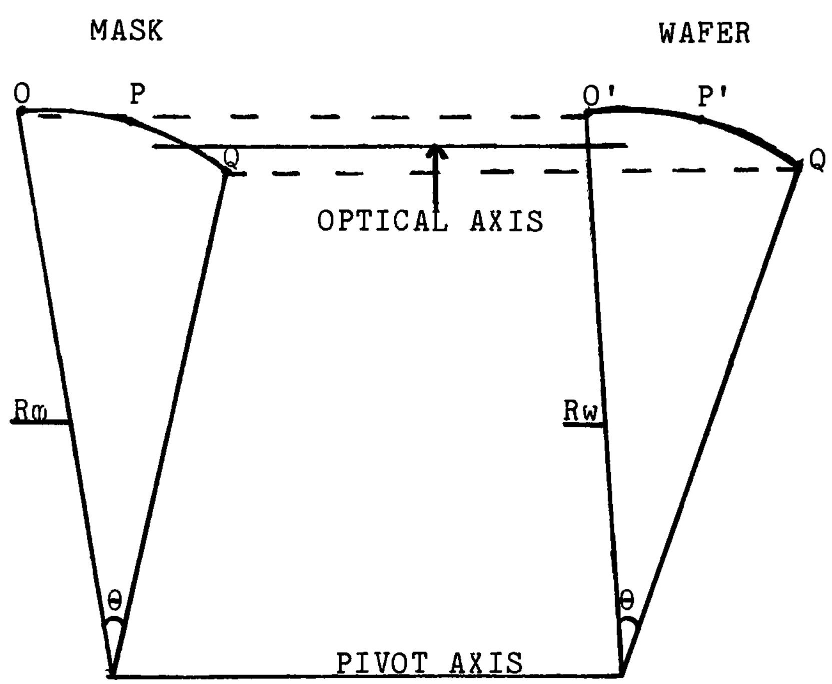

Figure 2. Mask, Tool, and Wafer Orientation.

During tool-to-itself studies two images(O'P'Q' and O"P"Q") are produced on the wafer. Manual alignment of the mask and wafer, prior to exposure, forces points P' and P" to coincide. Under ideal conditions, points O',O" andQ',Q" will also coincide as shown in Figure 3.

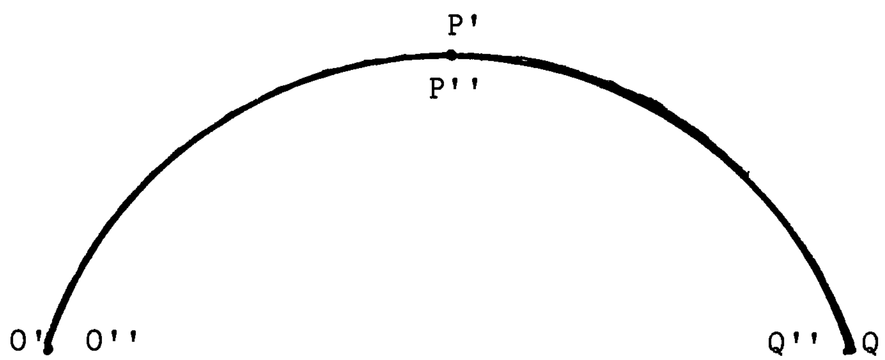

Figure 3. Location of Image Points Under Ideal Conditions(Rm = Rw).

However, the situation shown in Figure 4 often occurs in practice. Here, the pivot axis, AB, is not parallel to the optical axis, so Rw does not equal Rm. Manual alignment will still cause points O',P',Q' to coincide with points O",P",Q" provided that the mask is not moved between exposures. If the mask is repositioned between exposures, the non-parallelism of the optical and pivot axes will cause the two images on the wafer to occur over two different arcs of curvature as seen in Figure 5.

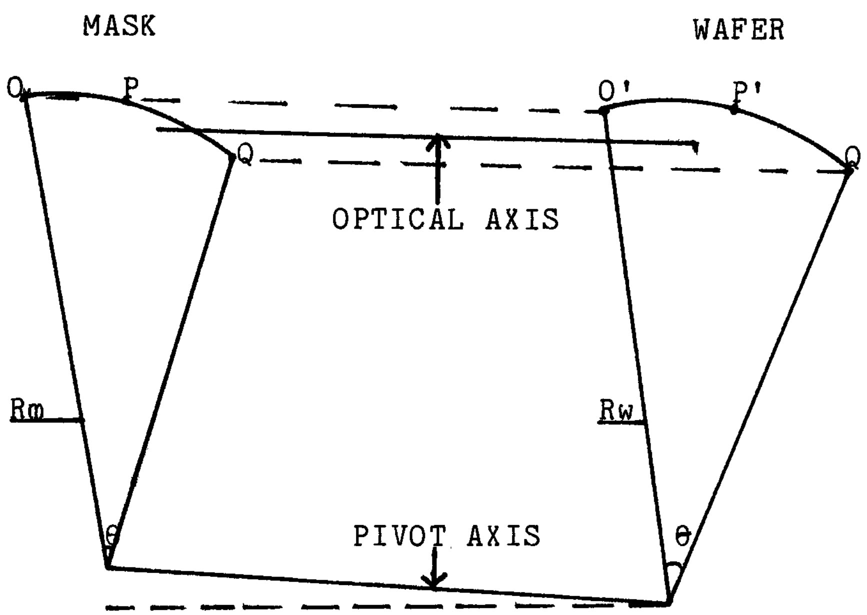

Figure 4. Non-parallelism Between Optical and Pivot Axes.

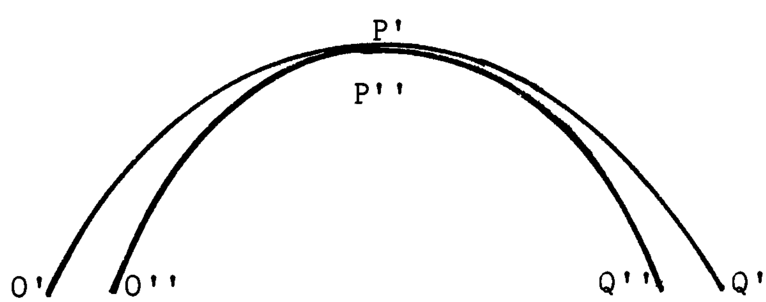

Figure 5. Location of Image Points When Rm ≠ Rw.

The effect just described will cause a systematic variation in overlay error across the sample, primarily in the horizontal direction as seen in Figure 5. This variation causes a non-zero magnification error to be seen along the horizontal direction, as will be described in the Experimental and in Appendix 1.

In summary, it was hypothesized that, under practical conditions, movement of the mask between two exposures would generate variations in the size of the observed magnification errors. In the experiment, existence of x and y magnification in tool-to-itself studies was first demonstrated. Experiments were then performed to prove or disprove the above mentioned hypothesis.

EXPERIMENTAL

Thirty wafers were obtained from co-workers by a verbal request. These wafers possessed an oxide layer, approximately 500 nanometers thick, grown on the silicon substrate.

The wafers were manually checked for flatness using a Tropel Wafer Flatness Tester. Only wafers that met the standard acceptable flatness of three microns or less were used, in order to minimize the possibilty of distortions due to surface irregularities or warpage.

The two types of resist used were also obtained from co-workers. The first type was an IBM proprietary high contrast resist. The other was AZ 1350J resist produced by the Shipley company.

The first portion of this experiment was intended to verify that measurable x and y magnifications would occur on a set of ten wafers made in a tool-to-itself experiment. The magnification values found on these samples were expected to be very similar as all variables in the experiment were be kept constant. These wafers were, therefore, used as a control for comparison against later experiments in which some parameters were allowed to vary.

The ten control wafers were precoated with A1100 (used to improve resist adhesion to oxide), baked at 100°C for twenty minutes, cooled for ten minutes, coated with approximately one micron of HC resist, baked for thirty minutes at 100°C, and cooled.

The correct exposure time (scan speed) was found by exposing, developing, and then examining a wafer under a microscope to see if the images were acceptable. Once the correct exposure time was found, the other nine wafers were exposed, developed in potassium hydroxide for three minutes, rinsed in distilled water for ten minutes, and dried in a spin dryer.

Next the wafers were baked for thirty minutes at 130°C, then placed in a 10:1 buffered oxide etch solution for eight to ten minutes to etch the image into the oxide layer. The first wafer had insufficient etching and therefore could not be used.

After etching the control wafers, the resist was stripped off. The eight useable wafers were then recoated, re-exposed, and developed as described above. Two wafers were accidently exposed prior to alignment, therefore, accurate overlay measurements could not be taken from them.

Overlay values were then taken from thirty-six specific sites, on each of the remaining six wafers, using an IBM proprietary method of measurement. The sites were chosen to give a thorough sample from each wafer. These values were then entered into a computer for anaylisis.

To calculate the amount of x magnification error across a wafer, a computer program used the formula $Mx = \frac{\partial O_x}{\partial x}$ where Mx = the magnification in the x direction, $\frac{\partial O_x}{\partial x}$ = the partial derivative of x overlay error with respect to x.[10] By substituting y values into the above equation the y magnification error was also calculated. See Appendix 1 for the derivation of the magnification formula. As previously stated, these magnification errors were expected to be similar for each wafer in the control set because no variables were changed from wafer to wafer.

The second portion of this experiment tested the hypothesis that mask repositioning between exposures changes the magnification error value. This was performed by exposing ten wafers, removing the mask from the exposure tool, reinserting it, and then exposing another set of ten wafers. To verify that changes in magnification were not due to changes in resist, but were due solely to mask repositioning, each set of ten wafers contained five wafers coated with HC resist and five wafers coated with AZ resist.

All of the wafers used in this portion of the experiment received their first exposure in one run. To ensure continuity, only the second exposure involved mask removal.

Processing of the HC resist wafers was the same as previouslv mentioned. However, the exposure time was increased for the AZ resist wafers because AZ resist is less sensitive than HC resist and, therefore, needs a longer exposure time.[11] One AZ wafer was accidentally exposed prior to alignment. Therefore, it was not used. The AZ wafers were developed in AZ developer for one minute.

After processing, overlay measurements were taken on the thirty-six sites per wafer for seven AZ wafers. These measurements were analyzed as above described and values for magnification error were again generated. Reading of the HC wafers was then to commence, however, it was found that there had been improper resist adhesion. This was thought to have been caused by the precoat, A1100.

All of the wafers that had not been read for overlay were then stripped and recoated, using the same precoat.

They were re-exposed and developed. The A1100 was found to still be ineffective, so a new one was tried. The wafers were stripped and precoated with HMDS. They were coated and re-exposed. This time there were five HC wafers and two AZ wafers in the first group. The second group contained four HC wafers and four AZ wafers.

At this time, the equipment used to measure overlay was modified for more efficient use. Because of these modifications all of the wafers were reread to ensure consistency. Magnification values of the wafer images were then generated by the computer. These values were graphed versus the wafer number to show the pattern difference between the different groups. A "t" test was then performed on the data to determine whether or not there was a significant difference between the average magnification values of each group.

RESULTS

The magnification values calculated in this experiment had units of parts per million (ppm) which is equivalent to microradians. A sample of x and y overlay values for a single wafer(SD38) can be seen in Table 1. These overlay values were taken from thirty-six specified sites on the wafer, and were used to calculate an x-magnification of 3.0ppm and a y-magnification of -1.8ppm for this sample. The resulting x and y magnification values for all of the wafers can be seen in Table 2. Figure 6 shows the x magnification values and Figure 7 illustrates the y magnification values plotted against the sample number.

A students "t" test was performed on the magnification values to test for significance of the differences in magnification between the groups of wafers. See Appendix 2 for a sample calculation using the "t" test. There is said to be a significant difference between two values if the calculated value of "t" is greater than the value of "t" given in a "t" table. As can be seen in Table 3 a significant difference was found between the magnification values of the different groups.

Table 1. X and Y Overlay Values for Wafer SD38

X Overlay	Y Overlay
-.459	.000
-.442	-.044
-.439	.000
-.349	.044
-.371	.153
-.396	.176
-.329	.263
-.307	.307
-.281	.393
-.175	.263
-.219	.154
-.218	.131
-.306	.044
-.308	.000
-.351	.000
-.391	-.043
-.351	-.088
-.286	-.088
-.173	-.130
-.152	-.130
-.198	-.088
-.219	-.044
-.174	.000
-.217	.087
-.087	.087
-.109	.130
-.087	.174
.087	.217
.022	.087
.000	.130
-.044	.044
-.044	.044
-.087	.087
-.087	-.087
-.044	-.044
-.087	-.217

Table 2. X and Y Magnification Values

Group	wafer	Mx(ppm)	My(ppm)
1	RP21	4.9	- .8
1	RP22	3.9	-1.3
1	RP23	5.2	-1.9
1	RP24	5.4	- .6
1	RP25	5.0	- .9
1	RP26	4.5	-1.2
2	SD21	1.1	-1.4
2	SD22	.9	-1.9
2	SD23	.5	-1.1
2	SD24	.2	- .6
2	SD25	1.0	-1.5
2	SD33*	1.4	-1.4
2	SD34*	1.1	- .9
3	SD36*	3.3	-1.3
3	SD38*	3.0	-1.8
3	SD26	3.6	-1.8
3	SD27	2.6	-2.0
3	SD28	3.1	-2.2
3	SD29	3.3	-1.9
3	SD40*	2.5	-1.7
3	SD32*	3.6	-1.5

* - Wafers coated with AZ resist.

Table 3. T Test Values.

Groups	T,Table	Tx, Calculated	Ty, Calculated
1-2	3.106	33.148	2.492
2-3	3.012	27.599	7.903
1-3	3.055	14.869	8.860

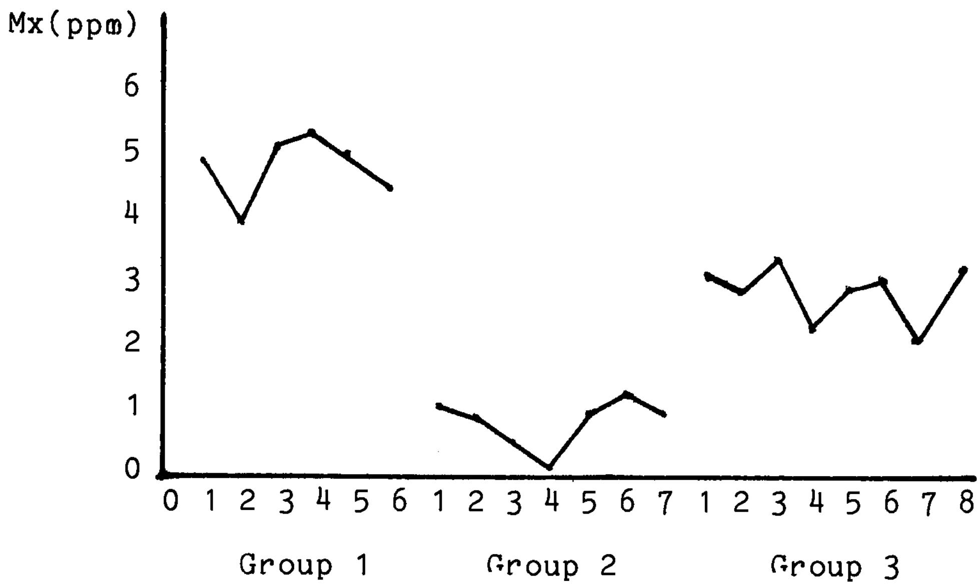

Figure 6. X Magnification Versus Wafer Number.

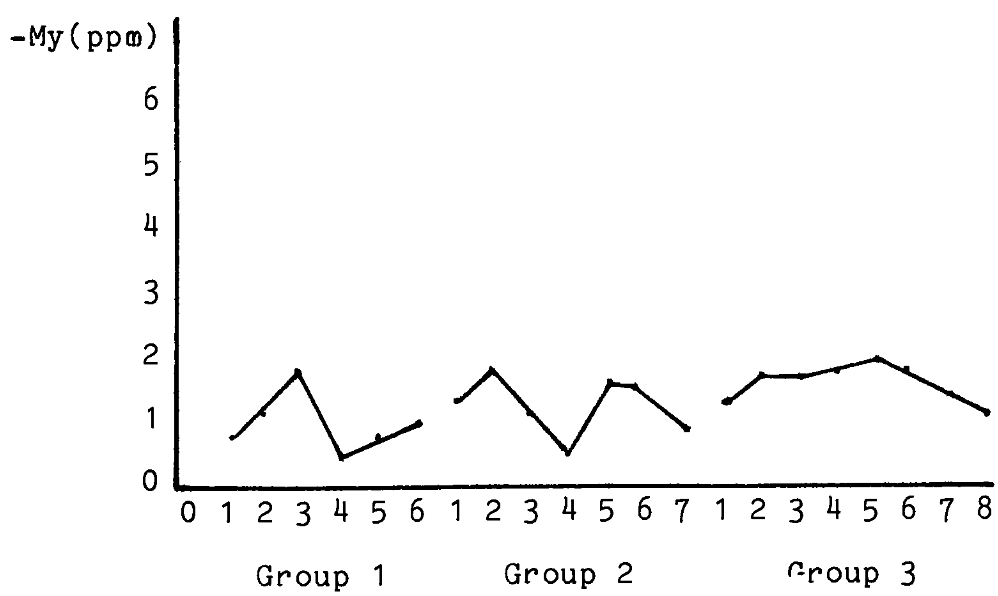

Figure 7. Y Magnification Versus Wafer Number.

DISCUSSION

It can be seen from Figure 6 and Table 3 that there is a significant change in the x magnification when the mask is repositioned between groups of wafers. As seen in Figure 7 and Table 3 the y magnification remained fairly constant. This serves as a good control because the y magnification should not change due to mask repositioning and shows that no other factors such as changes in temperature had a great effect on the y magnification. These results, therefore, verify the hypothesis that mask repositioning has a significant effect on observed magnification error.

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[9]R.Chappelow, personal comm.

[10]D.S.Perloff, "A Four-Point Electrical Measurement Technique for Charactizing Mask Superposition Errors on Semiconductor Wafers," I.E.E.E. Journal of Solid State Circuits, SC-13, 441 (1978).

[11]R. Peck, personal comm.

[12]Micralign Model 210/230 Maintenance and Repair Instructions, Perkin-Elmer Corporation, Norwalk, Conn., 3-5(1980).

APPENDIX 1

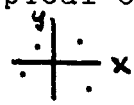
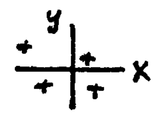
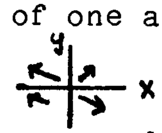
On a typical overlay wafer, Image 1 is etched in the oxide: 

Image 2 is in the developed resist: 

When the two images are laid on top of one another an overlay vector map is formed: 

The set of vectors on a wafer forms an overlay vector field, $\bar{O}$. Mathematically, $\bar{O} = \bar{r}_o + \begin{pmatrix} m_x & \theta \\ -\theta & m_y \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \bar{\epsilon}(x,y)$

Where, $\bar{r}_o$ = the alignment offset vector, m_x = amount of x magnification, m_y = amount of y magnification, θ = the rotation of the images from each other, $\bar{\epsilon}(x,y)$ = a random function.

Separating into x and y components yields:

$$O_x = r_{ox} + m_x \cdot x + \theta \cdot y + \epsilon_x(x,y)$$

$$O_y = r_{oy} - \theta \cdot x + m_y \cdot y + \epsilon_y(x,y)$$

Mx is then solved for by taking the partial derivative:

$$\frac{\partial O_x}{\partial x} = \frac{\partial}{\partial x} r_{ox} + \frac{\partial}{\partial x} m_x \cdot x + \frac{\partial}{\partial x} \theta \cdot y + \frac{\partial}{\partial x} \epsilon_x(x,y)$$

$\frac{\partial}{\partial x} r_{ox} = 0$ since r_{ox} is constant over the wafer.

$$\frac{\partial}{\partial x} m_x \cdot x = m_x \cdot \frac{\partial}{\partial x} x = m_x \cdot 1 = m_x$$

$$\frac{\partial}{\partial x} \theta \cdot y = \theta \cdot \frac{\partial}{\partial x} y = 0$$

Since $\epsilon_x(x,y)$ is a random function, the average value of $\epsilon_x(x,y) = 0$ over the sample. The average value of $\frac{\partial}{\partial x} \epsilon_x(x,y) = 0$ over the sample.

The final equation becomes $\frac{\partial O_x}{\partial x} = m_x$

Thus, Mx can be found by plotting Ox against x, and finding the slope.

APPENDIX 2

To determine whether or not mask repositionig had a significant effect on magnification values a "t" test was used in the following manner. First the average x and y magnification was found for each group. Next, the equation

$$S = \sqrt{\sum_{j=1}^{N} \frac{(x_j - \bar{x})^2}{N}}$$

was used to calculate the standard deviation. Where N = the number of samples in each group, x_j = a sample, and $\bar{x}$ = the average of all the samples in one group.

Comparisons of the magnification errors for each group were made using the equations,

$$\sigma = \sqrt{\frac{N_1 S_1^2 + N_2 S_2^2}{N_1 + N_2 - 2}} \qquad t = \frac{\bar{x}_1 - \bar{x}_2}{\sigma x \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}}$$

where s = the standard deviation.

The first comparison was made between the x magnification values of groups 1 and 2. The average value for Group 1 was found to be 4.82 and the standard deviation was .245. The average x magnification value for Group 2 was .89 and the standard deviation was .141. The formula was then used, where, N_1 = 6, s_1 = .06, N_2 = 7, and s_2 = .02. T was then calculated with $\bar{x}_1$ = 4.82, $\bar{x}_2$ = .89, σ_x =.213, N_1 = 6, and N_2 = 7. This resulted in the value 33.148 as seen in Table 3.

Vita

Sarah Dolan was born in Glens Falls, New York on April 23, 1961. She attended Southampton College for two years prior to transfering to Rochester Institute of Technology in June of 1981. During the summer of 1982 she obtained experience in the field of photomicrolithography at International Business Machines Corporation. It was at that time that she initiated her thesis work.

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